NGST "Microglitch" Assessment: Radiation-Induced Transient Effects in Infrared Focal Plane Arrays

OTHER SECTION OF THIS DOCUMENT THAT ARE STILL BEING WRITTEN INCLUDE:

3. The Infrared Space Observatory (ISO) Experience

4. Bennett NGST Analysis

5. SIRTF Ground Testing

6. Transport Codes

7. Array Modeling

8. Glitch Estimates

9. Radioactive Impurities

10. Testing Recommendations

1. Introduction

Goddard Space Flight Center's Radiation Effects and Analysis Group (REAG) has been tasked by the Next Generation Space Telescope (NGST) Project Office to aid in their assessment of all NGST radiation effects issues. This includes effects on microelectronic, photonic, and sensing devices. Some of the expected effects will be assessed using tools and approaches that we are well acquainted with, and others are unique to the NGST mission and will require significant research and development efforts. This document is intended to be an evolving document that will be updated frequently to communicate our progress, conclusions and recommendations to the Project Office and other involved parties on a continuous basis throughout the assessment.

1.1 Purpose of the Study

This study focuses on the anticipated impact of the space radiation environment on the infrared sensor arrays. Flight experience and ground testing performed for other programs show that infrared focal plane arrays (IRFPAs) are susceptible to transient effects and degradation due to dark current activation (hot pixels) and total-ionizing-dose (TID). The IRFPAs must meet or exceed stringent (science-driven) performance requirements in the presence of the background cosmic ray environment and possibly even during energetic solar particle events (SPE).

Very low total noise requirements have been defined for the integrated detector systems (IRFPA plus electronics). The NGST project has requested that assessment of the susceptibility of the IRFPAs to radiation-induced transients be given highest priority. Special emphasis is to be placed on gaining an understanding of the rate and temporal behavior of low-level transients that have an amplitude of the order of the total noise floor ('micro-glitches'). Low-level transients at the 1-sigma level are difficult, if not impossible, to reliably detect and remove in post-facto processing of science data. The effective noise floor of the images might be raised above the total noise requirement regardless of how well the system performs in a radiation free environment.

All significant sources of transients due to ionizing particles and photons will be considered, including primary particles and secondary ionizing radiation emitted as a result of interactions between primary particles and the shielding and structural materials surrounding the arrays. Ionizing radiation originating from latent trace radioactive isotopes in the materials used to construct the focal plane assemblies and nearby structures (including optics) will be examined. The density of hits in a maximum integration time science exposure (currently 1000 seconds) will be quantified in order to determine whether the arrays will be in compliance with the cosmic ray pixel upset requirement.

In addition, we recommend that the tolerance of the arrays to total ionizing dose effects be investigated. With modest amounts of shielding, the predicted total ionizing dose in the NGST arrays will be less than 10 krad(Si). Data that we have gathered from various sources suggests that a total ionizing dose of 10 krad(Si) has minimal impact on the performance of infrared arrays. Even so, because dose will be delivered randomly by particle radiation, there will be inherent temporal and spatial nonuniformity, and dose deposition and effects at the pixel level will need to be considered carefully. In view of the ultra-low noise and very high sensitivity required for the NGST detector systems, total ionizing dose effects that have negligible impact for less sensitive applications might not be insignificant for NGST. Displacement damage effects may also be of concern since the majority of the 10 krad(Si) dose will be due to protons. One strategy for the mitigation of transients due to secondary particles or photons emitted by the materials surrounding the arrays might be to decrease the thickness of the shielding. The trade-off in this strategy is an increase in the total ionizing dose and displacement damage in the arrays.

1.2 The Study Team

A team has been assembled to assess radiation effects in the NGST infrared arrays. Team members, contact information and areas of responsibility are shown in Table 1. (A discussion of the tasks is given in Section 2 of this document)

Table 1 Members of the NGST Radiation Effects Study Team.*

Team Member	Affiliation	Responsibility	Email
Robert Reed	GSFC/NASA	Overall lead	robert.a.reed@gsfc.nasa.gov
James Pickel	Consultant to NASA/GSFC	IR array modeling, testing and radiation effects	jim@pickel.net
Paul Marshall	Consultant to NASA/GSFC	Physics of damage mechanisms	pwmarshall@aol.com
Thomas Jordan	EMPC & Consultant to NASA/GSFC	Radiation transport physics/codes	tjordan@empc.com
Bryan Fodness	GSFC/NASA Contractor	Radiation transport codes	bfodness@pop500.gsfc.nasa.gov
Ray Ladbury	GSFC/NASA Contractor	Radiation effects	rladbury@pop500.gsfc.nasa.gov
Bernie Rauscher	STScI	Reduction of Radiation Effects Data	rauscher@stsci.edu
George Gee	GSFC/NASA Contractor	Data Analyst	George.B.Gee@gsfc.nasa.gov
Craig McCreight	ARC/NASA	Radiation Effects Testing	cmccreight@mail.arc.nasa.gov
Janet Barth	GSFC/NASA	Space radiation environment	janet.barth@gsfc.nasa.gov
Christian Poivey	GSFC/NASA Contractor	Space radiation environment and effects	cpoivey@sgt-inc.com

* We would like to thank Michael Jones for his contribution to this effort.

1.3 The Radiation Environment

The natural space radiation environment is complex and dynamic. In a low altitude low inclination orbit, a spacecraft will be subjected to electrons and protons trapped in the van Allen radiation belts. A spacecraft in a polar LEO orbit will be exposed to solar particle events (SPEs) and to an increased flux of galactic cosmic rays (GCRs) as it flies through the (geomagnetic) polar auroral regions. At the high altitude L2 Lagrange point for NGST, deflection of SPE protons and GCRs by the geomagnetic field will be minimal. Although NGST will be above the van Allen belts, the spacecraft will still be exposed to an unattenuated flux of SPE protons and GCRs. Temporal variations occur in the particle populations on both short and long time scales. These variations are driven primarily by the long-term solar cycle and by short lived, but occasionally intense, solar particle events.

Specifics of the predicted L2 radiation environment for NGST are captured in NGST Document 570 [1]. GCR particles are primarily comprised of protons with a compositional breakdown of ~83% H and ~13% He with the remainder being either electrons (3%) or heavier ions (1%). Cosmic ray energies can extend well above the TeV range. For an assumed shielding thickness of 100 mils equivalent aluminum, the predicted energy integrated GCR flux for all ion species is ~5 ions/cm^2/s. The typical SPE proton abundance is ~95% with a small alpha (He++) component of ~5% (by number), although the composition may vary from event to event. SPE particle energies extend to hundreds of MeV for protons, and up into the GeV range for heavy ions (Z>1). A worst-case energy-integrated flux of ~1.9x105 ions/cm2/s behind 100 mils of equivalent aluminum shielding is predicted during the peak of a solar particle event

1.4 Radiation Effects of Concern for IRFPAs

In addition to the radiation effects that affect room-temperature microelectronics, including particle-induced transients and degradation from total ionizing dose (TID) and displacement damage, infrared focal plane arrays are subject to as some concerns arising from the specific mode of operation of scientific IRFPAs, their cryogenic operating temperature, and the unique device physics of the detectors. Below we present a brief discussion of some of these effects that are applicable to NGST.

- IRFPAs often operate near the physical limit of low noise and low signal. Consequently, low level transients (microglitches) due to ionization events from the background particle radiation environment are a noise concern. In reality a distribution of events will occur with various durations and magnitudes. The magnitudes will range from just above IRFPA noise floor to transients that are very large compared to the noise floor. We believe that the detector array, because of the larger active volume, is the dominant source of transients. However, ground test data and on-orbit experience suggests that the ROIC can also contribute to the transient problem.

- Long recovery times (seconds to minutes) have been observed in some bulk photoconductive (PC) Si FPAs after they have been hit by heavy ions. Although this is most likely due to dielectric relaxation in the detector, slow recovery in the ROIC cannot be ruled out because of the very low NGST operating temperature. At temperatures below ~20 K, carrier freezeout occurs in regular CMOS processes, and a host of anomalous effects have been observed.

- The cryogenic operating temperatures that readout integrated circuits (ROIC) require to achieve adequate sensitivity in the infrared make these detectors more susceptible to TID, because charge trapping (in oxides) is more efficient at low temperatures. The inherently thinner gate oxides of submicron CMOS, make such technologies inherently less vulnerable to charge trapping, so NMOSFET edge and field leakage currents are often the dominant TID degradation.

- Detector technologies of interest to NGST can be divided into photovoltaic (PV) devices such as HgCdTe or InSb and photoconductive (PC) devices such as extrinsic Si (Si:X, where X is a dopant such as As or Sb). Low dose-rate-induced drift in responsivity occurs in bulk PC Si detectors. This problem can be reduced, and perhaps eliminated, by using impurity band conduction (IBC) Si detectors. For both PV and PC technologies, TID damage is not typically a concern for the ionizing dose levels expected for the NGST. Displacement damage can be a concern for operation in high proton environments, and can cause decreased mean responsivity and increased mean dark current. Extreme damage events are sometimes seen as increased dark current in the affected pixel, often referred to as a "hot pixel."

- Low dose rate induced global offset in the output has been seen in many FPAs. Offsets on the order of millivolts are seen for dose rates comparable with the trapped proton belts or solar particle events. Current speculation on the physical mechanism that leads to these low-dose rate offset suggests that it results from charging effects in the ROIC—probably substrate charge that affects the MOSFETs and effective gain.

We have been directed by the project office to focus on effects that might cause an increase in the noise floor of the IRFPAs above the NGST total noise requirement – called the "microglitch issue".

1.5 NGST Array Technologies and Requirements

The baseline design for the NGST instrument complement calls for separate imaging channels specialized for the near infrared (NIR: 0.6 μm – 5 μm) and mid-infrared (MIR: 5 μm – 27 μm) spectral bands. The arrays to be deployed in the NGST instruments have not yet been selected. Detector development programs are actively underway at Rockwell and Raytheon, the two prime vendors for the IR arrays. In addition, trade studies of the integrated optical trains and IR detectors for the NIR and MIR instruments have not been completed. Still, based on maturity and flight heritage, the array technologies under consideration are known with reasonable certainty.

For imaging in the NIR spectral regime, hybrid arrays based on either mercury-cadmium-telluride (HgCdTe or MCT) or indium-antimonide (InSb) material will be selected. An operating temperature of 30 K is being assumed for the initial design (NGST Document 641 states that an operating temperature of greater than 30 K is a desirable goal but not a hard requirement). The cutoff wavelength will be 5 microns. Extended short wavelength response to ~600 nm is desired to enable limited imaging capability in the visible. A thinned MBE CdZnTe substrate will most likely be required to achieve such extended visible response in the MCT arrays. InSb arrays are thinned by design. Four NIR imaging cameras are currently planned, each built around a 4k x 4k focal plane array (FPA). An individual 4k x 4k FPA will be a mosaic of 1k x 1k sensor chip assemblies (SCAs), although a mosaic of 2k x 2k SCAs is a possibility, should the technology mature quickly enough for insertion into NGST.

Extrinsic silicon arrays based on impurity band conduction (IBC) technology will most likely be selected for the MIR channel. IBC arrays utilize a thin, heavily doped photosensitive layer.

Heavy doping promotes hopping conduction of the carriers, resulting in enhanced quantum efficiency. A lightly doped silicon layer between the photosensitive layer and the electrode blocks the hopping current from reaching the electrode. More lightly doped photoconductive (PC) arrays must be considerably thicker to achieve quantum efficiency in the infrared comparable to that of IBC arrays. Because bulk PC arrays have a larger active volume than IBC arrays, bulk arrays are more susceptible to transients.

The leading IBC technologies are arsenic-doped silicon (Si:As) or antimony-doped silicon (Si:Sb). Both technologies have been extensively tested for the SIRTF program (see Section 4) and are reasonably mature for flight. The operating temperature of the arrays will be 6 K with a desired goal of > 6 K. The pass-band requirement is 5 μm to 27 μm for MIR imaging with a cutoff wavelength goal of 30 μm for spectroscopy. Pixel pitch size will be in the 18 μm to 30 μm range. One MIR imaging camera with a 1k x 1k FPA is planned. The 1k x 1k FPA will probably be a mosaic of 512 x 512 SCAs.

Table 2 shows a subset of the technology development specifications for broad-band imaging (see NGST Document 641 for the complete set of requirements, Reference 2).

Table 2. Abbreviated NGST IR array technology development specifications.

Performance Parameter	NIR Channel	MIR Channel
Total Noise	10 e- rms	20 e- rms
Operating Temperature	30 K	6 K
Pixel Pitch	18 μm – 22 μm square	18 μm – 30 μm square
Pass Band	0.6 μm – 5 μm	5 μm – 27 μm
Radiation Immunity	'causes minimal effect'	'causes minimal effect'
Cosmic Ray Pixel Upsets	< 18%	< 18%
Maximum Exposure Time	1000 seconds	1000 seconds

Note that the total noise requirement applies at system level rather than just at the output port of the array ROIC. The total noise goal for spectroscopy is even more ambitious: 3 e- rms for both the NIR and MIR channels.

Hard requirements for the dark current in the arrays have intentionally been left undefined to allow the development teams a limited degree of latitude in the trade space that encompasses all of the noise sources explicitly called out in Footnote 1 of Document 641. Note: Consider reproducing this footnote here and indicating which noise sources may be influenced by radiation and also what radiation related noise sources may need to be added to the list. For example, better read noise performance for the ROIC would provide more margin for dark current shot noise in meeting the total noise specification.

2. Roadmap

This roadmap presents a top-level discussion of our current thinking and plans to address radiation effects concerns for IRFPAs. Because unexpected circumstances and technical issues may arise—as in all leading edge research—deviations from this roadmap may be necessary.

We will report any such deviation to the project office as soon as possible. Although several details remain to be defined, we believe that this roadmap represents a reasonable approach to resolving the radiation issues associated with NGST.

A major factor for assessing the "microglitch issue" is the observed increase in output signal that occurs when a single ionizing particle passes through the IRFPA, resulting in a transient signal. This is a complicated issue for several reasons. For example, a single ionizing event in one pixel could increase the output signal for several nearby (OK??) pixels by charge spreading and cross-talk. We propose to examine these issues by observing the increased outputs of individual pixels when a single ionizing particle passes through the IRFPA. Both testing and modeling will be used to arrive at a detailed understanding how such ion strikes affect both the struck pixels and those nearby. We will characterize all transient events in this study, whether they be of large, small or micro magnitude, with NGST scientists and engineers determining how the predicted transient event characteristics affect instrument performance.

There are two IRFPA vendors currently under contract to develop candidate technologies, and there are multiple variants on the design approaches. The two ROIC candidates are the Rockwell Hawaii series and the Raytheon SB290. The Hawaii 2RG is intended for use with HgCdTe detector arrays for the near-IR channel at temperatures around 30 K. The SB290 is intended for use with Si:BIB arrays for the mid-IR channel at temperatures around 6 K and with InSb arrays for the near-IR channel at temperatures of about 30 K. Based on preliminary assumptions about instrument sheilding and design, we will carry out assessments of microglitch issues for each IRFPA. These preliminary studies are to be completed by January 2003. After the design is finalized, we will update our assessment of the "microglitch issue" using actual material and geometry configurations, along with assessing other radiation effects issues for the IRFPA.

The current roadmap seeks to determine the radiation environment near the IRFPA by evaluating contributions from several different sources, as described below:

- Galactic Cosmic Ray (GCR): The dominant source of radiation at NGST's L2 orbit during quiescent solar conditions is the GCR background. The GCRs originate outside our solar system so that the fluxes of these particles are essentially isotropic at the L2 orbit, which is beyond the influence of the Earth's magnetic field.
- Solar Particle Environment (SPE): When the Sun is "quiescent," most of the particles it emits lack sufficient energy to penetrate even a small amount of spacecraft shielding. However, during times of high activity, conditions occur that can accelerate a spectrum of charged particles with a large range of energies for varying durations. These disturbances are known as solar particle events. The durations of such events are usually between a few hours and several days. The average frequency of these solar events varies roughly sinusoidally with the eleven-year sunspot cycle, and several significant events will likely occur during a 7-year solar maximum interval.

- Spacecraft Generated (Secondary) Environments:
  - The prompt secondary particles produced by primary particles passing through spacecraft shielding may contribute significantly to the ionizing radiation environment. Secondary electrons generated in material near the sensitive volumes of the FPA are of particular concern as a source of low amplitude pulses.

- Heavy particles—such as protons, neutrons and heavy ions—can interact with nuclei in spacecraft structures and render them radioactive. These nuclei then decay with a characteristic half-life—emitting alpha particles, gamma rays and electrons and adding to the subsequent radiation environment. Radiation levels resulting from such induced activation depend on time and on spacecraft composition and geometry as well as on the primary radiation environment. Temporal variations in the induced activity levels can be quite complex, because they depend on both the build-up—which is driven by the primary radiation environment—and on a potentially large number of activation products, each with its own decay rate. For relatively short-lived nuclei, equilibrium radiation levels fairly quickly. However, longer-lived products would increase over the mission. Moreover, increases in the primary environment due to SPEs would result in potentially significant increase in secondary radiation levels that would gradually decay over time. Accurate modeling of activation may go a long way toward not only predicting the secondary environment, but also toward suggesting materials and design guidelines that avoid NGST's science goals being compromised by activation.
- We are also concerned with the possibility that decay products of naturally occurring radioisotopes present in the NGST structures could contribute to the microglitch rate. Whether these radioisotopes are present as impurities (e.g. uranium contaminating beryllium) or by design (e.g. high Z dopants such as Th that are sometimes used for their optical properties), their effects will require modeling, and the results of these models well be used to suggest controls to ameliorate adverse effects.

2.1. Top Level Goals for the Microglitch Assessment

The goals of the microglitch assessment can be summarized as follows:

- Review existing data. We will review existing ground based and space based data sets to help formulate the specific issues to be addressed. Although we will focus on IR detectors, other potential issues may be addressed as they become apparent.
- Review previous estimates of "microglitch" rates. Charles Bennett has produced a series of documents that attempt to estimate the "microglitch" rate expected in the NGST's IRFPAs. We will review this estimate, attempt to understand the underlying data as well as the estimate's assumptions, and assess the implications of the results.
- Determine testing needs and support radiation testing. Based on the review of the existing data, the Bennett estimate for the "microglitch" rate, and the NGST requirements, we will evaluate the need for testing and make recommendations to the project. During this segment of the study we will not limit our recommendations to testing only for the "microglitch issue". We will also consider other test issues related to other radiation effects. We will develop the appropriate test sequence and methods to calibrate and validate the models that will be used to estimate the IRFPA response to the microglitch transients transient characteristics and participate in the testing as required. Part of this activity will involve the coordination of necessary test capabilities whether they are found within our group, within the NGST and NASA community, or elsewhere.
- Estimate transients for preliminary NGST design. We will develop the appropriate tools and models to estimate NGST transient characteristics, including event magnitude and duration, the degree to which events are spatially and temporally correlated, and the

evolution of transients during the mission. The approach will be based on NGST requirements, accurate space radiation environment predictions and radiation transport modeling, detector physics, knowledge of radioactive decay rates, knowledge of the interaction of radiation with NGST's structural materials, and test data on the specific device designs that may be used on NGST. Although the local particle environment at the detector—and hence the transient characteristics—will be uncertain to the degree that the NGST design is not finalized, this preliminary calculation wil allow us to validate our models and provide design advice for the final design.

- Recommend design practices to facilitate mission success. Estimating transient characteristics will require understanding of noise sources affecting mission performance. Because these sources will be affected by the observatory design to some degree, we will evaluate the impacts of design choices on noise sources including radiation-induced transients.
- Dissemination of results. Because the radiation assessment activity will require close coordination among several groups, the REAG will emphasize effective and timely dissemination of the analytic and experimental approaches as well as of results. This will be accomplished by means of biweekly telecons with the project, other topical meetings, documentation of each of the key activities of the group, and the maintenance of the other sections of this document that will capture our progress as it evolves. We will also document trips to IR characterization laboratories, IR array manufacturers, and drafts and final versions of test plans. Our objective is to perform our tasks with frequent interactions with the project office, instrument developers, detector developers, and detector characterization labs so that we maintain relevant focus and so that our results are understood by all interested parties.

An assessment of the "microglitch issue" for the final NGST design is not possible at this time and is not included in the current roadmap. However, after the final design is complete, we will perform the assessment if necessary. We will utilize the tools and models discussed in the fourth goal above to perform a more rigorous estimate for the transient rate including the size of the events, the degree to which they are spatially and temporally correlated, and the time dependence during the mission for the finalized NGST design.

2.2. Roadmap for Microglitch Assessment as of Feb 21, 2001.

The first four goals defined in Section 2.1 comprise the core of the roadmap. The first two activities facilitate development of background knowledge and understanding of the issues related to the transient phenomenon. The next two goals focus on defining an rigorous approach for assessment of the "microglitch issue" for NGST.

Figure 1 shows a block diagram of our current vision of how to estimate the transient rate, transient size distribution, and temporal behavior. Each block represents a task that must be preformed to complete the estimate. All of the tasks in this figure are structured to be inputs into the IRFPA model [Task 5.1]. Figure 1 is intended to help the reader see how the tasks fit together to result in an estimate of the transient characteristics. Task 2.1 and 2.2 are related to review existing on-orbit and ground based data on IRFPAs. Neither appear in Figure 1. We will give a brief description of each task next. Then in Section 2.3 we will define the timelines for each task.

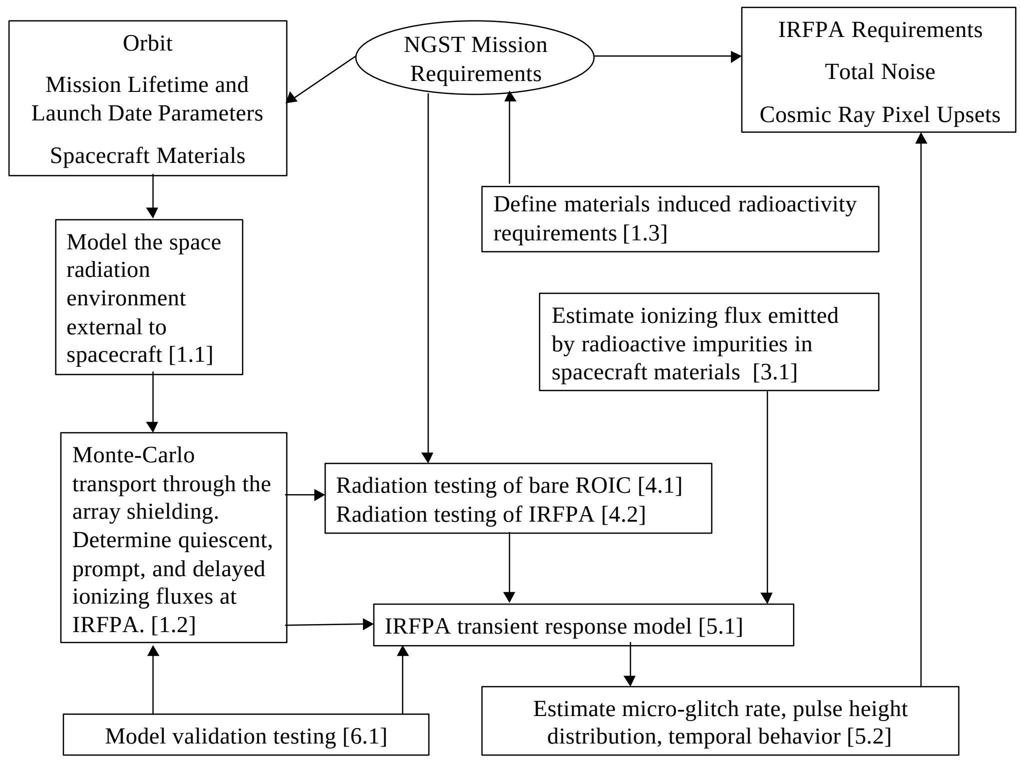

Figure 1.0. Block diagram of the portion of the roadmap that is focused on assessing the "microglitch issue".

<u>Task 1.1</u>
Model the external space radiation environment. The second revision to the model is detailed in NGST Document 540. These calculations need to revisited after the phasing loops have been defined.

<u>Task 1.2</u>
The external environment must be transported thought the spacecraft structure. The transport calculation must be carried out for GCR and SPE particle spectra and also for decay products from any radioisotopes present in spacecraft materials. As these environments transport through spacecraft materials they generate the prompt secondary and the longer-lived radioactive decay environments. The radiation environment at the IRFPA will be calculated by combining:

1. transport of the primary particle environment for the naturally occurring space radiation environment
2. transport of the primary particle environment for radiation resulting from radioisotopes in the spacecraft materials
3. transport of the resulting prompt secondary particle environment
4. transport of the resulting particle environment for induced radioactivity

The transport calculations will be carried out using at least two sophisticated Monte-Carlo codes called MCNP and GEANT. These codes and the details of the results will be described in the

Section 6. The results of these codes will be compared to one another and to ground test data (Task 6.1).

Task 1.3

This phase of the work will provide feedback to the project on the requirements for controlling the induced radioactivity that should be imposed on spacecraft materials. This concerns the induced radiation environment described in section 2 with emphasis on materials nearest the IRFPAs. Our approach will involve a modification of approaches that have been developed for other satellite missions such as the NEAR and MARS Surveyor 2001 projects. For those projects, the concern is contamination of gamma ray spectra measured near the Aros433 asteroid and the planet Mars. We will review the requirements levied on those instruments (for a total of 23 elements) and consider the need for requirements to limit materials that are known to contain elements that can become activated and add to the prompt primary and prompt secondary radiation noise anticipated for the NGST IRFPAs. We will also expand the scope of those previous efforts to encompass all anticipated sources of induced radiation that can influence the IRFPA noise levels at significant rates. In addition, we will review the practice employed by the MARS Surveyor 2001 mission of using B-10 or Li-6 shields to absorb thermal neutrons and thereby prevent them from interacting with elements (such as In) where they can lead to microglitch events.

Task 2.1

A detailed review of existing data on transient effects in IR detectors is ongoing. We will investigate two sources of data collected by the scientists and engineers working on the Infrared Space Observatory (ISO – primarily a European designed and developed instrument) flight program and the Space Infrared Telescope Facility (SIRTF – a NASA developed instrument) radiation ground test effort. We will provide a summary of the ISO and SIRTF "experience". We will continue our evaluation and review of existing data, and this document will be updated as needed to describe new findings. For example, we are reviewing the possibility of obtaining on-orbit radiation induced transient data collected by HST CCD's during dark field exposures. The short summary is simple; "glitches" have been observed, both in ground test data and on-orbit data. These data emphasize the need to assess the impact of transients on the NGST noise floor.

Task 2.2

We will examine the NGST "microglitch" rate assessment provided by Charles Bennett, reviewing the assumptions underlying the estimate.

Task 3.1

This task seeks to estimate the ionizing flux arriving at the detector from radioisotopes present in spacecraft materials that can arrive at the detector The emphasis is on the development of control for materials that will be nearest the FPA assemblies. Similar controls are often implemented for terrestrial low background detector facilities, where the concern is that trace amounts of naturally occurring radionuclides may produce unacceptable contamination of measured signals. We will consider known radioactive decay products for the elements expected in candidate NGST spacecraft materials to predict the environment at the IRFPA. This requires detailed knowledge of the types of materials, the impurities typically found in the materials, and the location of each material relative to the IRFPA. As an example, we have been cautioned that beryllium, unless it is processed using special techniques, will contain trace levels of radioactive uranium that will contribute to the FPA noise rate. Also, optical glasses that utilize high Z elements for refractive index control are known sources for contamination from thorium decay products.

Task 4.1

This task concerns radiation testing of the ROIC. There are two IRFPA vendors being considered by the NGST project, each with multiple variants on the design approaches. The two ROIC designs under consideration are the Rockwell Hawaii series and the Raytheon SB290. Each candidate ROIC must be assessed at the expected operating temperatures.

The first phase of the radiation effects testing is to collect preliminary transient event data using laboratory button sources. The test will be done at the Ultra-Low Background (ULB) Facilities and at NASA Ames Research Center (Craig McCreight's group). The ULB facilities have been chosen by the NGST project office to perform ultra-low background measurements on the ROIC technologies. The University of Hawaii (Don Hall's group) has been chosen to assess the Rockwell devices, while the University of Rochester (Judy Pipher and Bill Forrest's group) has been chosen to assess the Raytheon devices. Ames has or will have the necessary capabilities to test both Rockwell and Raytheon devices. Each ULB has agreed to provide images that contain ground level GCR-induced events as they occur. REAG, each ULB facility and Ames will develop the testing techniques and formalize a written procedure for these tests. The data from these GCR tests will be sent to Bernie Rauscher of STScI for analysis, REAG will support STScI with data analysis. These data will be used in three ways 1) to gain a preliminary indication of the performance of each lot split when exposed to a radiation environment, 2) to assist in the development of the model of IRFPA response to transient radiation and 3) potentially to assist with assessing the robustness of error correction codes. This testing is important, because it will provide a "first look" at IRFPA sensitivity as well as providing an initial basis for comparison of the sensitivities of candidate ROIC designs. However, this data is no substitute for controlled proton and/or heavy ion testing of the ROICs that show the most promise for the NGST FPAs. Such proton and heavy-ion tests will be needed to assess the radiation response of candidate devices and to calibrate and validate our models.

The second phase of the testing involves understanding proton and heavy-ion induced charge contamination of the ROIC unit cells. REAG, ULBs and Ames will develop a test plan that describes the goals and procedures for testing the ROICs with protons and heavy ions. Ames Research will be performing these test with support from REAG and the ULB facility personnel. These data will be sent to Bernie Rauscher of STScI for analysis, REAG will support STScI with a data analysis. The timelines in Table 3 assume only one test per ROIC type. As of now, we have developed a white paper that describes our goals for this testing.

It is recognized that transient effects in the hybrid array will likely be dominated by ionization in the detectors. Testing of bare ROICs is required to isolate the transient behavior of the readout from that of the hybrid as a whole. The testing will be performed on ROICs that closely resemble the selected flight devices from each vendor. .

Task 4.2

This task deals with radiation testing of the Rockwell and Raytheon IRFPA assemblies. (Note: the recommendations that follow are currently under review)

As with the ROIC testing, we recommend that the first phase of IRFPA radiation effects testing begin at the respective ULB facilities. These tests will be similar to those performed on the ROICs, a dark field measurement immediately followed by collection of dark frames during gamma particle exposure. REAG, the ULB facility, and Ames will develop the test procedures as needed. These data will be sent to Bernie Rauscher of STScI for analysis. REAG will support STScI with data analysis.

The second phase of the planned IRFPA testing examines proton and heavy-ion induced charge contamination of the IRFPA. A test plan will be developed that describes the goals and procedures for testing the IRFPA with protons and heavy ions. The timelines in Table 1.0 assume only one test per IRFPA type. REAG, the ULB facilities and Ames will develop a test plan for the hybrids that is consistent with NGST project requirements the results of the ROIC testing, the model validation needs, and the radiation environment expected at the IRFPA. Each IRFPA will be a hybrid that represents the candidate flight device as closely as possible, with the constraint that the need for early information may warrant testing with developmental hardware. Ames Research will be performing these tests with support from REAG and the ULB facility personnel. These data will be sent to Bernie Rauscher of STScI for analysis. REAG will support STScI with data analysis

<u>Task 5.1 and 5.2</u>

These tasks center around modeling the IRFPA response to radiation induced transients, which will be used to assess the impact of the transients on the noise floor for the NGST mission.

Inputs to this modeling include the external radiation environment (Task 1.1) and its transport through the material surrounding the IRFPA (Task 1.2), along with the ionizing flux produced by decay of radioisotopes present in spacecraft materials near the IRFPA (Task 1.3).

The radiation test data for the ROIC (Task 4.1) and the full IRFPA (Task 4.2) will be used for validation and calibration of the transient response model. It is not practical to test these devices for every energy and particle type encountered in space. Rather, ground-based data allows the experimenter to perform controlled experiments using mono-energetic, unidirectional beams of a single ion species. These data can then be used to calibrate the model for the particle species, test energies used in the test. The known physics of energy loss and ionization and charge collection in the IRFPA material can then be used to predict on-orbit performance.

FPA Charge Collection Model (Task 5.1)

The device-level impact of radiation-induced transients is charge injection into individual pixels. Assuming that the radiation environment is defined in terms of particle type, energy and angle of incidence, modeling noise glitches requires determination of the spatial and temporal charge collection across the array, with specificity to individual pixels. The charge generation is dominated by the detector because of its relatively large volume, but the ROIC can also contribute.

This problem is complicated by the following effects: 1) the charge generation is not uniform along the path of the ion, 2) the electric field is not uniform throughout the detector collection volume, 3) the collection volumes overlap for a detector array, and 4) there is temporal dispersion in charge collection. To render the problem tractable, some simplifying assumptions can be made.

The charge generation is assumed to be proportional to pathlength through the detector collection volume. This is probably a reasonable assumption for primary protons and heavy ions in the space radiation environment. For low energy particles, it may be necessary to account for energy loss along the path. It is also reasonable to assume that the ion paths are straight. For low energy electrons, a reasonable assumption is that the entire electron energy will be absorbed within a volume near its point of impact, i.e., the pixel that is struck. The collection volume can be divided into a drift region, where the electric field is high and a diffusion region where the field is low. The drift region corresponds to the depletion region in the PV detectors or the depleted layer in IBC detectors. The diffusion region is usually bounded by the thickness of the IR active layer. For example, in HgCdTe on CdTe substrate, the thickness of the HgCdTe layer bounds the charge collection region. The overlap of collection volumes can be accounted for by dividing the array area into the pixel sizes specified by the pitch. Temporal dispersion for charge collection is not an issue for long integration times such as will be used for NGST since the charge collection processes are complete in picoseconds for drift collection and nanoseconds for diffusion collection. However, there still could be relatively slow device response that could persist through reset. We will not know if this mechanism is a problem until testing is performed. If persistence through reset does occur, the impact on the mission will be assessed. That is another issue and will be dealt with separately from the charge collection modeling.

Modeling radiation generated noise in the detector array reduces to the problem of determining the charge generation within a diffusion length of the detector active volume as the particle passes through and loses energy by ionization, and the spatially dependent charge collection on a pixel-by-pixel basis. A first-order model to address this mechanism has been developed by Aerospace Corporation and calibrated by proton experiments with CCDs[1 2]. The model assumes that all charge generated in the depletion region is collected by the pixel that is struck and charge generated in the diffusion region is collected by the struck pixel and adjacent pixels by diffusion. The diffusion charge collection model by Kirkpatrick[3] is used to calculate the diffusion charge. The total charge collected by any pixel is the sum of the depletion charge and the diffusion charge.

Noise Predictions (Task 5.2)

Predicting radiation induced noise in the detector arrays for the NGST mission can be accomplished by developing a charge collection model similar to that discussed above and coupling the model to an input file of particle hits. After transporting the external environment

[1] 1 T.S.Lomheim, R.M.Shima, J.R.Angione, W.F.Woodward, D.J.Asman, R.A.Keller and L.W.Schumann, “Imaging Charge-Coupled Device (CCD) Transient Response to 17 and 50 MeV Proton and Heavy Ion Irradiation,” IEEE Trans. Nucl. Sci., Vol. 37, No. 6, P. 1876, December 1990.

[2] T.E.Dutton, W.F.Woodward and T.S.Lomheim, “Simulation of Proton-Induced transients on Visible and Infrared Focal Plane Arrays in a Space Environment, SPIE, Vol. 3063, p.77, 1997.

[3] S.Kirkpatrick, “Modeling Diffusion and Collection of Charge from Ionizing Radiation in Silicon Devices,” IEEE Trans. Elec. Dev., Vol. ED-26, p. 1742, 1979.

through the material surrounding the FPA, an LET file will be generated based on the particle type and energy and the target properties. The LET file will feed into a particle hit file to generate the statistically determined hit events. The particle hit file will consist of Monte-Carlo generated particle hits, with the particle type, particle energy, spatial location, and angles (angle from normal and azimuth) of incidence. With such an environment file, the array charge collection model can be exercised with Monte-Carlo-based statistical assumptions about the incident particles to predict the focal plane 2-D image response during the NGST mission.

If device temporal response persists longer than an integration time, this fact will need to be considered in determining the overall noise response. Knowledge about the persistence of a transient disturbance of pixel charge will have to be generated from proton and heavy ion test data on flight-like hardware since there is insufficient knowledge to determine this *a priori*. The charge contamination data and the temporal persistence data will form the base of information needed to assess the noise impact on the mission.

Task 6.1

There are two modeling efforts that must be validated. The first is the transport of radiation through spacecraft structures [Task 1.2]. This includes a validation of the portion of the prompt and the induced environment produced by the naturally occurring space radiation environment. The second is the modeling of the transient response of the IRFPAs [Task 5.1 and 5.2].

We plan to validate the transport codes for specific spacecraft structure materials, (e.g., Al, AlBeMet) via radiation testing. The most likely option is to use test setups designed specifically to measure primary and secondary products from this type of interaction. We have been in contact with several groups (internal and external to GSFC) regarding this type of validation test, and are in the decision-making mode as to how to proceed. We will most likely opt to leverage the test setups and testing schedules of one of these groups.

We plan to validate/refine the IRFPA modeling codes in three ways:

- Utilize small laboratory gamma sources (and possibly alpha) in the ULB facilities to obtain first-look radiation transient data for the ROICs and possibly full hybrids.
- Form a partnership with the team developing the WFCIII instrument for the Hubble Space Telescope (HST). They have plans to test their IRFPA (near IR with Hawaii 1R ROIC and Rockwell HgCdTe detectors) in the summer 2001. The HST/WFCIII team is considering the possible impact of transients in the IRFPAs to science data. We plan to leverage resources from both projects to develop a test sequence that meets both projects needs.
- The final method, and the ultimate test of the models, is to predict the performance of the NGST IRFPA when exposed to particle beams. We will use the testing opportunities described in Tasks 4.1 and 4.2 to validate and refine our models.

2.3. Timelines for Microglitch Assessment

Table 1.0 provides a draft of the timeline for each major task in the roadmap. We are currently on schedule. The timeline was developed to provide feedback to the project prior to the detector downselect. We fully intend on providing this feedback on schedule provided that test articles are delivered timely.

Table 3. Draft of timelines for major tasks.

		FY2000				FY2001				FY2002				FY03			
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1			
Task 1.1	Model space radiation enviroment external to spacecraft	■	■	■	■												
Task 1.2	Monte-Carlo transport environment through shielding			■	■	■	■	■	■	■	■						
Task 1.3	Define Induced radioactivity requirements					■	■	■	■								
Task 2.1	Review of existing data			■	■	■	■	■	■								
Task 2.2	Review of Bennett assessment			■	■	■	■	■									
Task 3.1	Estimate ionizing flux emitted by radioisotopes in spacecraft materials						■	■	■	■	■						
*Task 4.1	Radiation testing of bare ROIC					■	■	■	■	■							
*Task 4.2	Radiation testing of IRFPA						■	■	■	■	■	■					
*Task 5.1	IRFPA transient response model			■	■	■	■	■	■	■	■	■	■				
*Task 5.2	Estimate micro-glitch rate, pulse height distribution, temporal behavior											■	■	■			
*Task 6.1	Model validation testing							■	■	■	■						

* Note: Timelines for tasks 4.1 – 6.1 rely on timely delivery of appropriate test articles.